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Cost Impact of Residue Sampling And Collection Strategies for Drug and Explosive Residues

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ABSTRACT

Screening operations for illicit drug or explosives residues comprise two basic processes: 1) sampling and collection of the residue on an appropriate matrix, and 2) analysis of the sample or residue by an analytical device. Commercially available analytical devices require an initial capital investment. The analysis process is not labor intensive. Conversely, the sampling and collection process is a labor intensive process with high consumption of expendables. Two basic sampling and collection methods, with several variations, are employed in the field screening operations: wipe sampling and vacuum sampling. Both methods are preferred over the other for specific screening scenarios. An engineering analysis backed by field screening experience shows that significant cost differences arise with each method. Without trading-off data quality and for identical sampling strategies, a variation of vacuum sampling incurs the least cost by a significant margin over wipe sampling and other vacuum sampling operations.

BACKGROUND

The development of techniques to collect field samples of residues for analysis with today's illicit drug or explosives detectors has been left to the users of these instruments. Manufacturers appeared to focus their attention on the analytical instrument. This has led to very sensitive (sub nanogram for cocaine), fast (5 seconds), and reliable performance (low false positive/false negative rates). The performance of the entire process of sample collection, preparation, introduction, analysis, and interpretation is reduced from the detector performance itself. The sampling strategies (methods and techniques) used to collect residue samples significantly impact the operational cost of the effort. The sampling strategies need to be evaluated in the context of what the user is going to do with the analyses results. In this paper we discuss the merits and shortcomings of various collection techniques and show the cost impacts of each method. We begin by examining two very common sampling scenarios.

SAMPLING SCENARIOS

The paper describes two sampling scenarios which the authors suggest represent two diverse operational constraints. One scenario involves sampling targets where time is not a significant factor. An example of this would be looking for illicit drugs in high school lockers. The number and surface areas of the lockers are large and sampling techniques are dependent on thoroughness (minimizing false negatives) and avoiding cross contamination (a major source of false positives [1}).

The second scenario involves sampling of targets where time is a major constraint. An example of this would be sampling checked luggage for explosives at an airport. The number of pieces of luggage, the variety of surfaces, orientations, and the need to sample and analyze within six seconds (FAA design goal for single luggage) are constraints that shape sampling and analysis strategies.

SAMPLING AND DETECTION OPERATIONS

Sampling operations concerning contraband drugs or explosives are presently limited to hand held collection modules. Automated walk through portals, break cargo, or luggage systems have been under development by the Federal Aviation Administration. The ideal contraband residue collector system would be hand held, battery operated, and very flexible in acquiring residue samples, and analyzing and interpreting the results within seconds. This tool does not exits.

However, the maturation of field chemical residue instruments for illicit drugs and explosives has created the possibility of large scale deployment of detection systems. Yet, this deployment has legged behind expectations. Some of the reasons for this are that the illicit drug contraband interdiction community has experienced false positives at too high a rate to encourage routine use of these systems. The counter terrorism community is more concerned with the potential for false negatives cargo, or luggage systems have been under development by the Federal Aviation Administration. This paper concentrates on hand collection of residue samples. The authors assert that the analysis of the hand held collection process needs to be performed prior to attempting to design and engineer an automated system.

Contraband packages, whose exterior surfaces are contaminated with residues (illicit drugs and explosives) are detectable by the inspection of the exteriors of break cargo and luggage. The search for illicit drug residues in these situation is one of interdiction. The search for explosives residues in these scenarios are for security and interdiction.

There are four other scenarios that one searches for explosives residues [2]:

1. At post-explosion scenes and on items recovered from such scenes
2. On suspects clothing and hands
3. In premises - on work surfaces, tools, shelves, etc.
4. In vehicles - either suspects' vehicles.

Thus sample collection can come from a variety of surface materials which present unique problems to the collector. For example, break cargo and luggage can be leather, cloth, cardboard, plastic, aluminum, etc. The surfaces can be rough or very smooth. The surfaces may be susceptible to marring by abrasion or the action of solvents used in the collection process. The surface can be stationary or moving. The surface may not be readily available to the collector and requires physical contact. The target surface may be located considerable distances from the analyzer. There may be a time constraint, such as with luggage at airports or with perishable commodities at ports of entry.

SAMPLING PROTOCOL CONSTRAINTS

Sampling is the most important and least engineered aspect of the detection process. The engineering process must begin with a solid understanding of the requirements of the user. The collection process may need to be thorough, have no sample cross contamination, and meet the constraints of the sampling scenario (time, location, etc.). The most appropriate sampling tools and protocol are determined by the detection scenario and the detection requirements. Defining these requirements is the first step in the detection operation. The requirements determination process identifies the essential constraints, such as time, manpower, location, time-on-target, etc. In many way cases the user cannot define the requirements adequately. Thus the service provider can best obtain an insight into the requirements from questioning how the user intends to use the information resulting form the analyses.

For the purpose of this analysis we evaluated two scenarios. One, is collecting residue samples from stationary objects (high school lockers) and surfaces for forensics. Two, is collecting from cargo, mail, parcel post, break cargo, or luggage moving on a conveyer for interdiction of contraband.

Each of these sample collection scenarios present unique problems to the collection team. In the case of sampling high school than for false positives.

The goals of Instrument manufacturers is to develop highly sensitive and relatively specific instruments. Manufacturers have incorporated software algorithms that enhance the specificity of the instrument. Yet false positives and negatives associated with sample collection and transport have been ignored. This paper provides an overview of an engineering analysis of the sample collection issues. Sampling techniques, materials, prevention of false positives, and minimizing false negatives are discussed.

The authors suggest three primary operational goals of the sampling collection process:

1. Collect residue of interest
2. Minimize collecting other substances that may mask or cause false positive responses in the instrument
3. Collect and transport residues without loss or contaminating the collector

These goals and how to achieve them are discussed next.

SAMPLE COLLECTION METHODS

There are two basic methods of residue sample collection: wiping and vacuuming. Wipes can be wet or dry. Vacuuming can be with or without contamination control.

Wipe sampling employs some type of collection material that is suitable to the surfaces to be sampled, compatible for transferring the collected sample to the instrument desorber, disposable, and inert to the detector if input directly into the instrument desorber or if a chemical extraction processed is used. Wipes used are Teflon, cloth (typically cotton), and filter paper. Wipes can be used in conjunction with dilute solvents, such as alcohol. The choice of solvents is important since operationally one is concerned with damages target surfaces, with chemical reactions between the solvent and the chemical residues of interest, the temperature effects if direct desorb is used while wipe pad is wet, and concern for exposure effects to humans through contact and through inhalation.

Vacuum sampling employs a collector nozzle, a filter, a filter holder or support, an exit port and a vacuum pump. There are two types of collector nozzles available: controlled and uncontrolled.

A controlled nozzle is one which employs air boundary layers throughout the nozzle to eliminate aspirated particles from striking and sticking to interior surfaces of the nozzle. The boundary layer tends to focus aspirated particles to the filter matrix with out loss. An uncontrolled nozzle will become contaminated with use as particles will strike and adhere to the interior surfaces of the nozzle. With uncontrolled nozzles sample residue is lost. The lost material has two negative affects on the operation. One effect is that false negative results are more likely, since the mass of residue aspirated could be near the lower detection limit of the instrument, and the loss of some or all of this mass could lead to a missed opportunity of detection. The second negative effect is the possible occurrence of false positives from the dislodging of previously collected samples, which were deemed negative but did indeed have residue that was lodged in the nozzle and dislodged by the new sample aspirated particles.

One manufacturer markets a hybrid sampler which employs a vacuum and a wipe strategy to sample surfaces. Upon analyzing this hand held collector, the authors concluded that the collector material used and the vacuum air velocity employed by the module were incompatible and that the device functioned primarily as a wipe mechanism.

Thus the state of collection methods for hand held modules are limited to a four choices, wet wipes, dry wipes, uncontrolled nozzle, or controlled nozzle surfaces. We next examine the techniques and scenarios where residue sample collection is needed.

CRITERIA FOR DETERMINATION SAMPLE COLLECTION METHOD

What is the best way to sample the surfaces of these articles, collect the residue, and transport the collected residue to an analytical instrument, which is usually located in the vicinity of the check point? The answer to this question is important for hand held, manual operations and for the design of automated sample collection schemes. To answer this question a set of criteria needs to be defined in quantitative terms. These criteria are derived from the detection requirement analysis.

This set on criteria is used to evaluate the sample collection options. The criteria list that the authors consider critical are:

- Time: How much time is allowed and needed to collect residue samples?
- Expendables: What expendables items are used and what are the logistics for keeping them readily available?
- Cost: What is the labor cost, expendable items costs, etc.?
- Detection: What is the minimum detection rate of the system?

- False Positives: What false positive rates can be tolerated and at what cost?

- False Negatives: What false negative rates can be tolerated and at what cost?

These criteria have different values the three collection scenarios and for the degree of importance placed on detecting and identifying the residue.

SAMPLING TOOL AND PROTOCOL IMPACTS

Specifications for sampling tools and protocols are a function of operational performance requirements. Sampling and collection technologies employed in residue sampling impact the performance of the analytical detector. The sampling, collection process has taken a back seat during the development of fast, reliable field residue detectors. The collector modules provided by detector manufacturers have severe contamination problems and are not field friendly, They lack engineering. The systems appear to have been developed as an after thought and then primarily for a laboratory environment rather than field sampling.
For example, one manufacturer supplies a hand vacuum that requires the users to assemble the collection filters in a clean environment. The filters are easily damaged once fabricated and are prone to coming apart do to poor assembling. These filters are fine in a laboratory environment where perhaps a handful of sample are run each day, but in the field the contraband screening requires sampling of hundreds of items such as suit cases in very short time spans.

The authors observed the contamination and operational problems while performing field trials with these devices and during hands-on experiments. Cross contamination and collection efficiency were found to be major operational specifications. These and other factors involved in achieving the objectives of sampling are discussed below.

Collecting the particles of interest. Ideally one would desire to collect residues of target materials only. However, this is most unlikely as particles of interest are very likely to be mixed and even adhered to other particles. The need to reduce the contamination of a given sample depends on a number of factors: the amount of target material mass available compared to other materials, the likelihood that contaminating materials could degrade, mask or otherwise invalidate an analysis, the sensitivity of the detection technology to the other collected particles.

The source of extraneous particles could be from dust, pollen, and from the collector matrix itself. The example of the impact of contamination of samples was reported by Revenue Canada [3]. Revenue Canada reported that when using the Barringer Ionscan and wipe sampling documents that signals obtained form cocaine and heroin place on a clean filter were compared to the signals obtained from the targets after the filter was rubbed onto a card which been filled out with inks. The degradation of the signals due to the presence of the ink was observed.

During wipe sampling of packages and mail in prisons also produced indications of procaine from the ink. This was observed by one of the authors in December 1996. The impact of rubbing unwanted chemicals unto a sample matrix may not be critical for situations where false negatives are not crucial to safety and security. But in situations where false negatives are disastrous, such as screening for explosives, the introduction of competing or masking chemicals could be a major problem. Tests such as those performed by Revenue Canada [3] need to be performed, but in the mean time vacuum sampling should minimize this problem.

Vacuum systems, however, to date have been the source of false positives as extreme care by the operator has been necessary to ensure nozzles are contamination free [4]. The dislodgment of contamination residue in subsequent sampling is source of false positives, which the manufactures have left to the operators to resolve via operating procedures. The operators have responded by trying various operationally inefficient procedures and ultimately most operators use wipe sample collection over vacuum sampling.

For any automatic collection process this is a major engineering constraint. Mechanical wipes must be disposable and compatible with the instrument's desorber. Vacuum nozzle's and residue transport segments must be free of contamination. The need for thoroughness in the collection processed must be defined for automated system design.

In situations where forensic analysis is needed, contamination-free vacuum modules would greatly expedite forensic sample analysis. The on-site systems would identify samples on or in which trace particles of explosives were detected, thus reducing the number of exhibits requiring laboratory analysis.

<u>Sampling Thoroughness and Speed.</u> Sampling thoroughness and time to sample are tradeoff parameters. The moving luggage or break cargo scenario requires very fast sampling rates. The FAA has specified that each luggage piece has to be sampled, the sample analyzed, the analysis interpreted in six seconds. Today's fastest of today's detector instrumentation (ion mobility spectrometry) takes five seconds to perform the analysis and interpretation functions. This leaves one second to sample the luggage and transport the sample to the instrument.

SAMPLING OPERATION OBSERVATIONS

Obviously, to meet the six second constraint, not all pieces of luggage on a conveyor can be sampled. Or if they all are to be sampled how can this be achieved? But this raises the question of the pieces selected for sampling how thorough need be the process? Do all surfaces need to be sampled? What percentage of a selected surface need to be sampled?

These basic questions have been left unstudied. The focus has and continues to be on improving the detector/interpretation process and on the characteristics of residues, by not on how the practical methods of collecting and transporting specimens to the detector. The authors have used various counter narcotics and explosives detectors in contraband searches at airports, border crossings, ports of entry, and in the work place. From these experiences we have made the following observations:

1. Drug contraband carrying containers whether from users or smugglers will have relative large quantities of illicit residue on them, thus thorough (100 percent sampling) is not necessary.

2. Explosives contraband containers will have relatively small quantities of residue on the exterior and thorough sampling is required.

3. Residues of interest will be found where people handle the container. For example, handles, zippers, belts, labels, and likely hand holds are the best place to sample. Sampling 100 percent of an article may not be necessary, but the authors do suggest that this area of study begs to be considered. Wipe sampling of specific high residue target areas can be performed very fast and thoroughly.

4. Wipe sampling requires a double transfer of the residue of interest. First the residue has to be collected by the wipe material, than transferred from the wipe material into the instrument detection module.

(The authors have observed that for the ion mobility spectrometers, wipe samples are themselves only partially sampled by the instruments detector module. For example, one cloth wipe has a surface area of 5250 square millimeters (mm). The surface area analyzed by the desorber of the instrument is less than 491 square mm or 9.3 % of the surface area. Users compensate for this in two ways. They try to analyze the most soiled part of the wipe or they try to remember to wipe the pressure point (where their finger was).

5. Wipe sampling is hazardous to the operator. Wiping articles can lead to cuts and bruises since the user must apply force to the surface. This is particularly hazardous for interior surfaces of luggage, where razor blades and hypodermic needles may be located.

6. Comparison of analytical results by the authors under operational sampling conditions showed:

a. targets that were vacuum and wipe sampled (clothing and metal lockers), the vacuum sample read higher mass present than did the wipe sample (Fortuna report to HARC Dec. 96).

b. wipe samples were positive four times when the vacuum samples were negative. In these cases the wipe sample was collected first.

c. There were no cases where the wipe sample was negative and the vacuum sample positive. This suggests that the vacuum sampler used, which used boundary layer counter contamination control, did not produce or transfer false positives. Laboratory test conducted by the authors of commercially available nozzles was a source for false positives.

7. Grouping of target samples using wipe sampling will cause cross contamination of residue from positive surfaces to clean surfaces. Vacuum sampling minimize the opportunity for transferring residue from one target surface to the another. The vacuum collector nozzle is the most likely source of this contamination.

EXAMPLES OF SAMPLING PROTOCOLS

Grouping of targets works when the prevalence of positive surfaces is low as seen in Table 1. The idea of grouping samples is to minimize the number of analysis performed by the instrument and at the same time increase sampling rates. One would group samples in sizes that would provide the probability of less than 0.5 that at least one of the group would test positive. When a group sample is negative, than no further analysis is needed. When a group sample is positive, than a new sampling strategy will be used. One such strategy if the grouping is five or less is to resample and analyze the targets individually. For larger target groups, one could form smaller groups and sample those together. Some of these groups may be negative. Groups that show positive then will require the individual targets to sampled and analyzed separately. Table 1. says that if the expected probability (prevalence) of positive targets is 0.4, that one could economically sample twenty together. If the prevalence is 0.135 (13.5% positives expected), than groupings of five can be used. If the prevalence is 7%, than a grouping of 10 is justified.

Table 1. Recommend sample group size as a function of prevalence.

GROUP SIZE	1% PREV.	4% PREV.	5% PREV.	7% PREV.	13.5% PREV.	26.1% PREV.
3	0.97	0.88	0.86	0.8	0.65	**0.4**
5	0.95	0.82	0.77	0.7	**0.49**	0.22
10	0.9	0.66	0.6	**0.48**	0.24	0.05
15	0.86	0.54	**0.46**	0.34	0.11	0.01
20	0.82	**0.44**	0.36	0.23	0.06	0

The economics of using grouping strategies for large number of items to be samples and whose expected positive rate is less than 26.1% is illustrated by the following example.

The sampling of high school lockers for illicit drugs with residue analyzers is an awesome task. Let us say, that the school contains 2000 lockers and we are to check for the presence of marijuana. The ion mobility spectrometer is an ideal analytical instrument for cocaine and methamphetamine, but it is much less sensitive for marijuana. The positive detection for marijuana requires the sampling team to analyze all samples with another technology, namely immunoassay kits designed to react to specifically to (THC) marijuana. These kits cost about $8 each. So if one were to sample each of the 2000 lockers with individual kits, the cost in kits alone would be $16,000. But, if one expected that 14% of student body were using marijuana, and of those users, half would use marijuana regularly enough to leave a residue on their lockers, then the expected prevalence is 7% (140 lockers).

Table 1. shows that a good sample size for this situation would be ten lockers at a time. Initially, 200 kits would be used at a cost of $1600. Of the 200 10-group samples 48% or 96 will test negative. Allowing the testing team to no longer have to deal with 960 lockers. However, there are 104 groups that contain at least one positive locker and the prevalence rate has nearly doubled to 13.5%. If one sampled all remaining 1040 lockers individually, the cost in kits would be an additional $8320. Thus the total cost in kits using this grouping strategy is $9,920 versus $16,000.

The savings in kits would be higher still, if a new group size were used. Table 1. suggests a logical sub group size of five. Re-sampling, in groups of five would (Table 1) means that 208 groups would be acquired and of these 100 (48.5 percent) would be expected to be zero. This step would cost an additional $1664 in kits. The remaining 108 groups of 5 lockers (5) would require individual sampling and analysis at a cost of $4,320. Thus the total investment in kits with this strategy would be $7684 versus $9,920 for the single grouping strategy. Grouping the remaining lockers by threes still would add additional savings.

The grouping strategy to sets of three requires 179 groups and $1432 in kits. Forty percent of these (71) will contain no positive lockers. This leaves 214 lockers to be sampled individually at a cost of $1928. The total cost for this strategy is $6,624.

There is another important sampling parameter that grouping of target improves is time. This is very important when screening airline baggage for explosives. The FAA has established a six second maximum time to sample a piece of luggage, have the sample analyzed, and the results interpreted. This is a very difficult time constraint. Especially, since the fastest analytical device (IMS) takes 5 seconds to analyze and interpret the sample. This leaves 1 second to sample a suitcase. Group sampling of luggage could be used to meet this condition, however.

The expected rate or prevalence of luggage containing explosive residues is most likely much less than 1 bag per 1000. We expect that the true prevalence of explosives in luggage is extremely low. But due to people who use nitroglycerin legitimately or as a heart medicine and other munitions experts, who travel we used 1 in 1000 pieces to have explosive residues at detectable levels.

This means that if we were to sample 10,000 bags, in groups of 100, with a prevalence rate of 0.001, that 99 groups will test negative and 1 group would have at least one positive piece. This also shows that the collection sampling time can be 5.95 seconds per bag, which is significantly longer than the one second per bag allowed if the bags were sampled individually.

CONCLUSIONS

1. Wipe sampling is the preferred sampling method by users of residue detectors

2. Residue detector manufacturers have pretty much ignore the sample collection and transport aspects of residue analysis

3. Vacuum sampling provides more flexibility in sample collection and transport than does wipe sampling

4. Grouping of low prevalence targets is economically justifiable

5. Group sampling is best performed through vacuum collection modules.

6. Vacuum sampling if used is best done with a boundary layer counter contamination function.

7. Collection costs are a function of the user requirement. In situations where false negatives are not critical, the protocol can be less vigorous. The high school locker sampling example shows that cost savings can be significant if group sampling is employed. Without group sampling the cost was estimated at $16,000 and only $6,624 with grouping. There many applications where these types of concepts can be employed and still meet the needs of the user.

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